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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line
systems for local and access networks

**Gigabit-capable passive optical networks
(GPON): Reach extension**

Recommendation ITU-T G.984.6



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Recommendation ITU-T G.984.6

Gigabit-capable passive optical networks (GPON): Reach extension

Summary

Recommendation ITU-T G.984.6 outlines the architecture and interface parameters for GPON systems with extended reach using a physical layer reach extension device such as a regenerator or optical amplifier in the fibre link between the optical line termination (OLT) and optical network termination (ONT). The maximum reach is up to 60 km with loss budgets of in excess of 27.5 dB being achievable in both spans.

Source

Recommendation ITU-T G.984.6 was approved on 29 March 2008 by ITU-T Study Group 15 (2005-2008) under Recommendation ITU-T A.8 procedure.

FOREWORD

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Recommendation ITU-T G.984.6

Gigabit-capable passive optical networks (GPON): Reach extension

1 Scope

This Recommendation concerns GPON systems with optical link budgets up to the logical limits of the transmission convergence (TC) layer. The increased optical capability, which includes both increased overall fibre length and increased overall splitting ratio, is referred to in this Recommendation as "reach extension". The primary concerns addressed are the increase of the loss budget and the management of optical impairments.

This Recommendation considers mid-span extension, which uses an active extension node placed in the middle of the optical network. The recommended parameters for the ODN(s) involved in this scheme are specified. Single-sided extension is considered as an improvement to the OLT interface, and is described in [ITU-T G.984.2] as amended.

The systems considered here must remain compatible with existing ONTs. Furthermore, the approaches should maintain compatibility with existing OLTs to the maximum extent possible. It is recognized that some modification of the OLT equipment may be necessary, but this should be minimized.

Two system architectures are considered: optical amplification, and opto-electronic regeneration. These can be viewed as providing reach extension at the physical layer. The key interfaces and functional blocks in each of these architectures are identified and specified.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.652] Recommendation ITU-T G.652 (2005), *Characteristics of a single-mode optical fibre and cable*.
- [ITU-T G.983.1] Recommendation ITU-T G.983.1 (1998), *Broadband optical access systems based on Passive Optical Networks (PON)*.
- [ITU-T G.983.3] Recommendation ITU-T G.983.3 (2001), *A broadband optical access system with increased service capability by wavelength allocation*.
- [ITU-T G.984.2] Recommendation ITU-T G.984.2 (2003), *Gigabit-capable Passive Optical Networks (GPON): Physical Media Dependent (PMD) layer specification*.
- [ITU-T G.984.3] Recommendation ITU-T G.984.3 (2004), *Gigabit-capable Passive Optical Networks (GPON): Transmission Convergence layer specification*.
- [ITU-T G.984.4] Recommendation ITU-T G.984.4 (2004), *Gigabit-capable Passive Optical Networks (GPON): ONT management and control interface specification*.
- [ITU-T G.984.5] Recommendation ITU-T G.984.5 (2007), *Gigabit-capable Passive Optical Networks (GPON): Enhancement band*.

3 Definitions

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ASE	Amplified Spontaneous Emission
BER	Bit Error Ratio
BW	BandWidth
CW	Continuous Wave
EONT	Embedded Optical Network Termination for management of the extender
GPON	Gigabit-capable Passive Optical Network
NGA	Next Generation Access
OA	Optical Amplifier
OBF	Optical Bandpass Filter
ODN	Optical Distribution Network
OEO	Optical-Electrical-Optical converter
OLT	Optical Line Termination
ONT	Optical Network Termination
ONU	Optical Network Unit
OTDR	Optical Time Domain Reflectometer
OTL	Optical Trunk Line
PLOAM	Physical Layer Operations, Administration and Maintenance
PMD	Physical Media Dependent
PON	Passive Optical Network
R/S	Optical network unit interface to optical distribution network
R'/S'	Extender interface to optical trunk line
SOA	Semiconductor Optical Amplifiers
S/R	Optical line termination interface to optical trunk line
S'/R'	Extender interface to optical distribution network
WBF	Wavelength Blocking Filter

5 Conventions

None.

6 Optical extension schemes and architectures

The basic PON architecture is shown in Figure 1. The OLT interfaces with multiple ONTs via the ODN. The OLT also provides interfaces to one or more SNIs, as well as the management system. The ONT interfaces with various UNIs. The only interfaces of interest to this Recommendation are those that face the ODN. Amendment 2 to [ITU-T G.983.3] and Amendment 1 to [ITU-T G.984.2]

specify the best practice loss profile for the ODN to be between 13 and 28 dB. The OLT-ODN and ONT-ODN interfaces for GPON are specified in [ITU-T G.984.2] (as amended). Indeed, most ITU-compliant PONs deployed today adhere to these Recommendations.

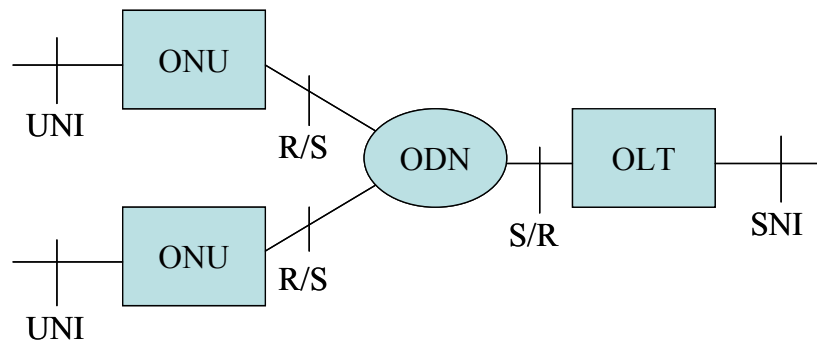


Figure 1 – Basic PON architecture

The architecture considered in this Recommendation is illustrated in Figure 2. A mid-span extender device is inserted between the ODN (compliant with existing PON Recommendations) and an optical trunk line (OTL), which is connected to the OLT. This architecture extends the reach of the PON by the length of the OTL, and may also increase the split ratio of the PON. However, it does require electrical power for the mid-span extender.

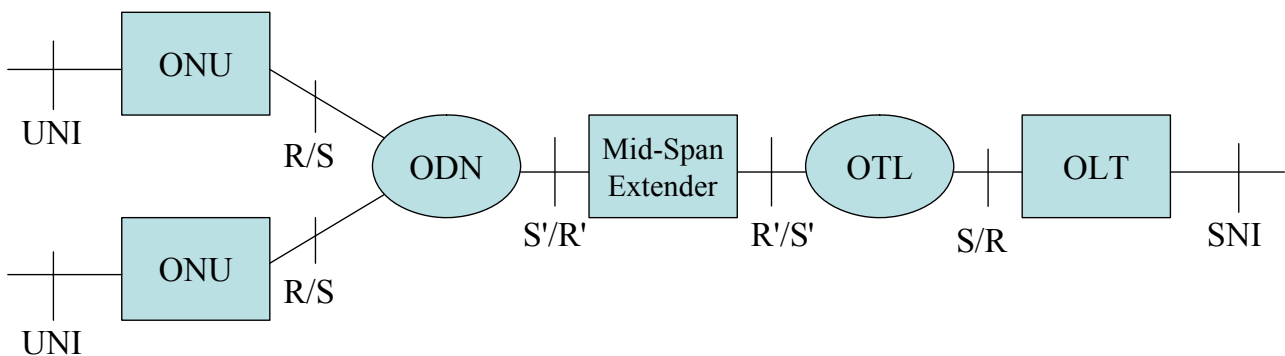


Figure 2 – Mid-span reach extension

There are several ways to implement an optical reach extender. There are two general classes of extenders. The first is an optical amplifier (OA), shown in Figure 3a, which provides gain in optical power. The second is an optical-electrical-optical (OEO) regenerator (Figure 3b), which receives an optical signal, reshapes and retimes it in the electrical domain and retransmits in the optical domain. Further hybrid schemes are possible, for example, to use optical amplification in the downstream and regeneration in the upstream, as shown in Figure 4a, or the reverse as shown in Figure 4b.

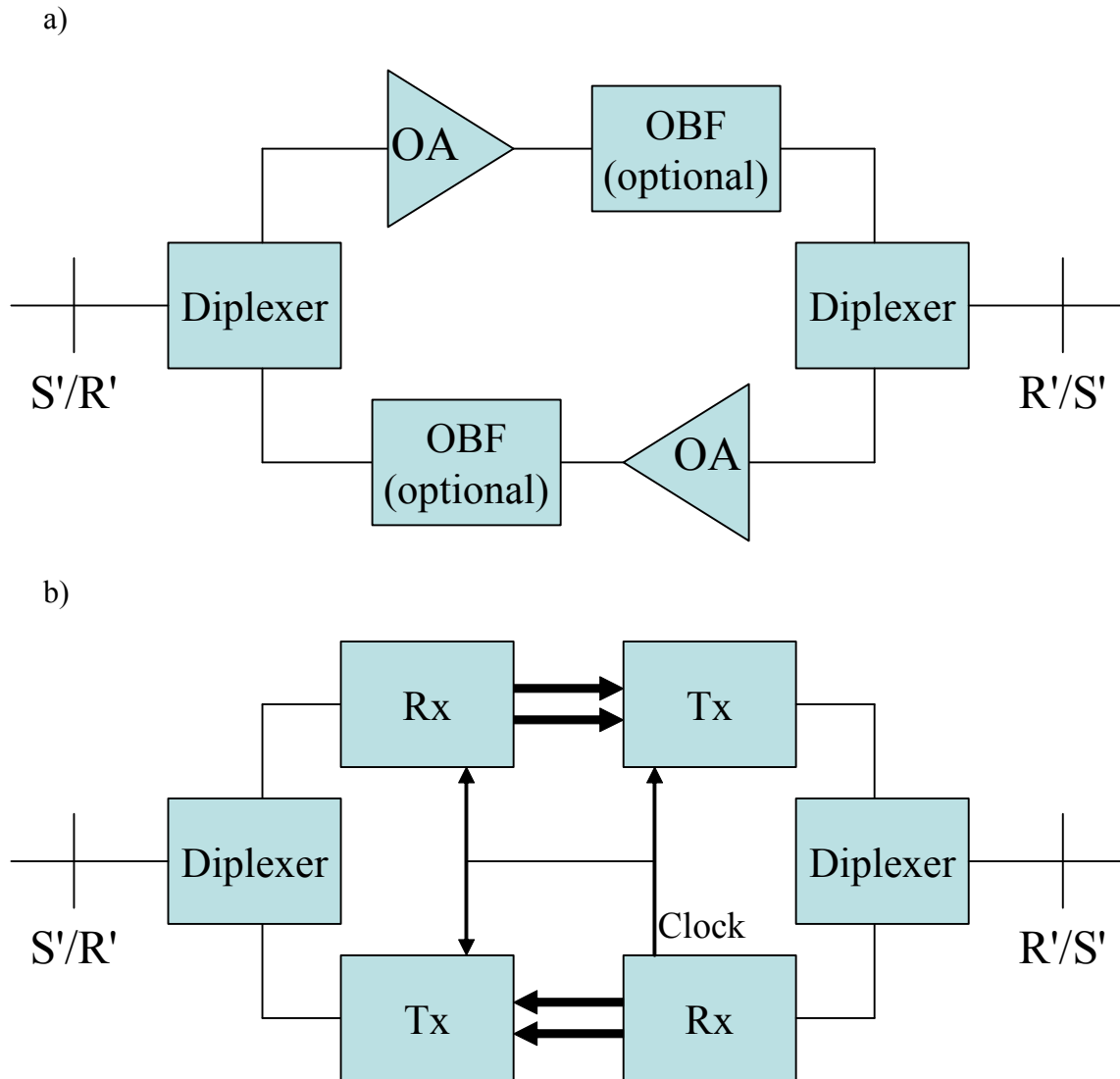


Figure 3 – The two basic extender architectures: Optical amplifier, repeater

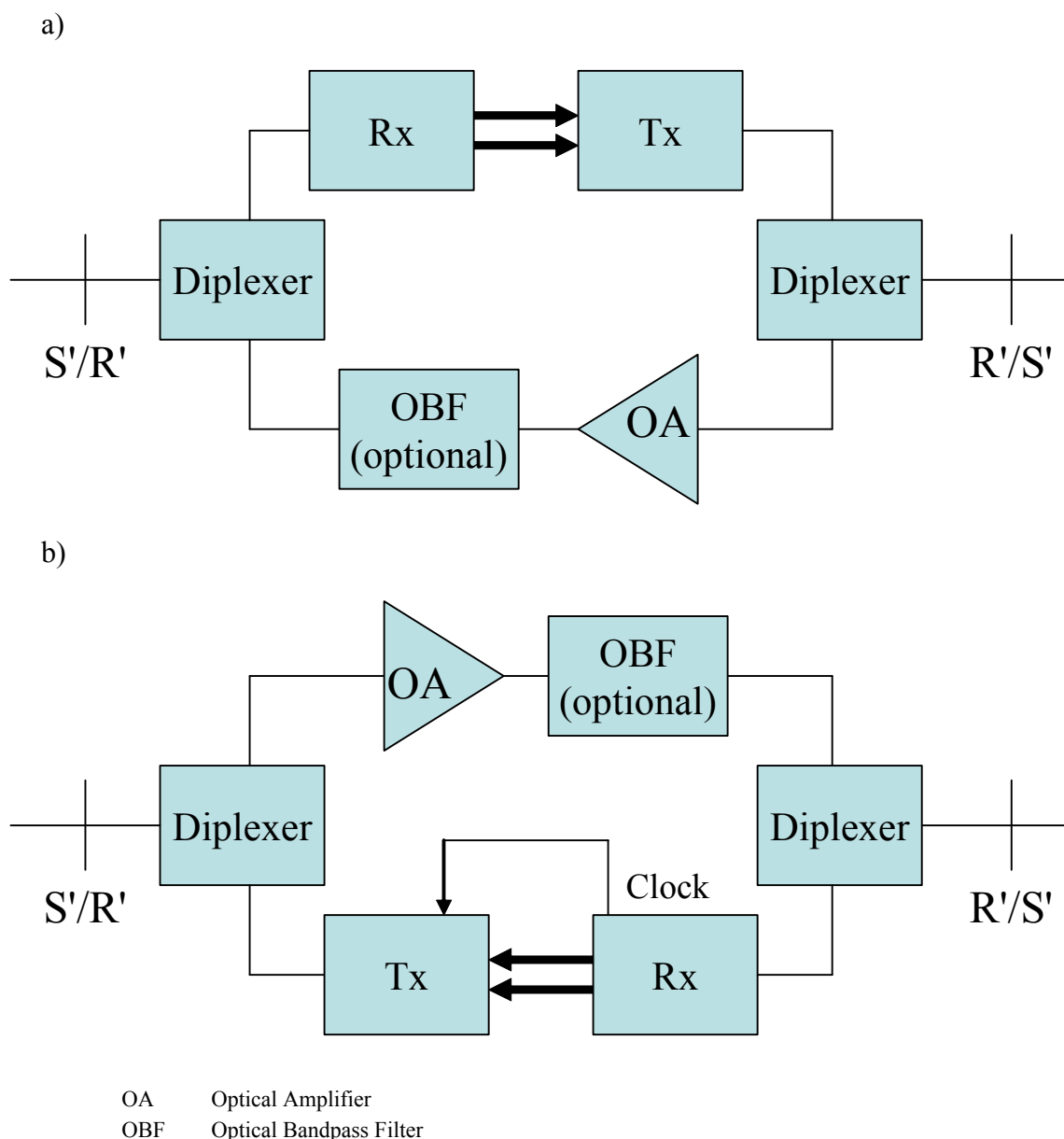


Figure 4 – Examples for hybrid extender architectures

6.1 OA-based reach extenders

Reach extenders based on optical amplifiers optionally may include optical bandpass filters (OBFs) in order to restrict the bandwidth of amplified spontaneous emission (ASE) generated by the optical amplifier, and thus reduce ASE-ASE beat noise and ASE-based power-offset (see Appendix I) in the optical receiver and achieve higher performance. If OBFs are used, restricted wavelength range for transmitters may be necessary. For options on restricted upstream bands, refer to [ITU-T G.984.5].

Due to the nature of OA-based reach extenders, the application range (useable trunk and ODN loss range) varies according to the parameters of the optical amplifiers used. The vendor has to provide sufficient data showing the key parameters (such as, e.g., maximum gain, minimum gain, saturated output power), the application range and applicable penalties due to ASE.

As there is no signal regeneration provided by OA-based reach extenders, ONT and OLT transmitters must provide a dispersion reach of up to 60 km.

An optical amplifier-based extender should include a complete embedded ONT (EONT) for management purposes, as shown in Figure 5. The EONT is connected internally by means of an optical tap coupler at the interface facing the OTL in order to keep the RE accessible even in case an optical amplifier fails.

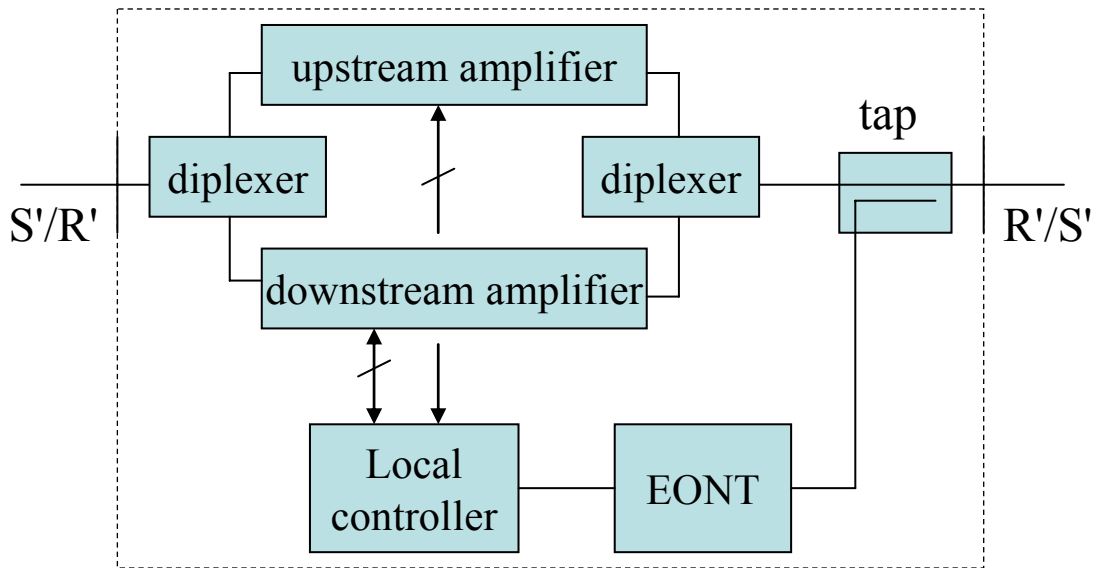


Figure 5 – OA-type reach extender with embedded ONT (EONT) for management purposes

6.2 OEO-based reach extenders

The signals passing through the OEO extender are re-timed (2R regenerators are not specified by this Recommendation). The timing reference for this function is the downstream receiver of the extender (see Figure 6). This timing is used to drive both transmitters and as a reference for the other receiver. This arrangement is identical to that used in SDH regenerator devices.

The presence of an OEO-based extender may require extension of burst overhead, which is automatically handled by the OLT via PLOAM messages (refer to clause 8.5). As the increase of burst overhead is bandwidth-relevant, upstream burst detection is supported by the aid of an embedded ONT (EONT, see Figure 6) which is used for management (see clause 7.2). In addition to the managing functions, the EONT may analyse the downstream signal and read the BW map in order to calculate burst-timing. In this way, a reset signal to the upstream burst-mode receiver can be provided, and the required burst overhead extension is kept to minimum.

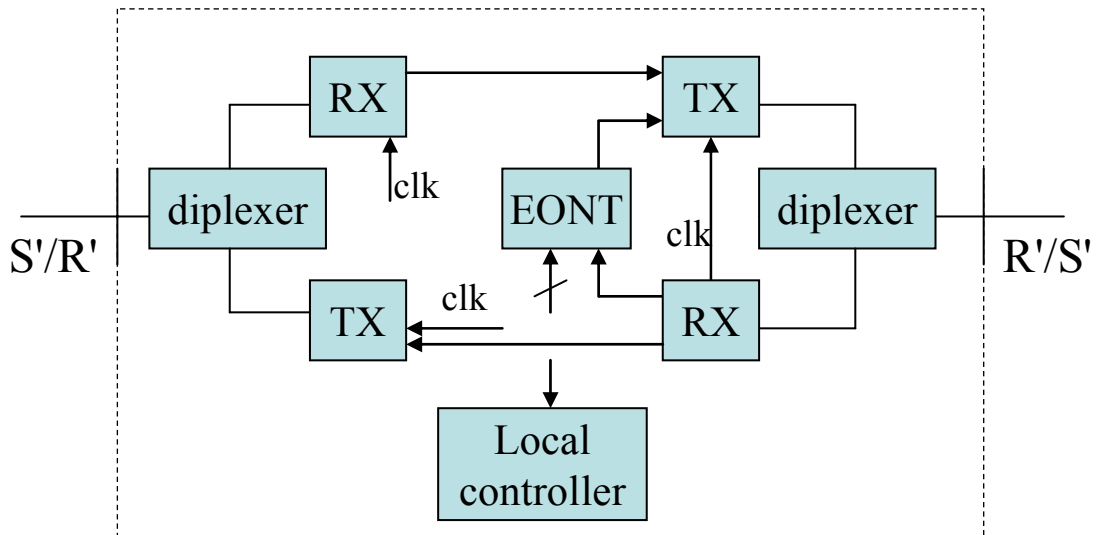
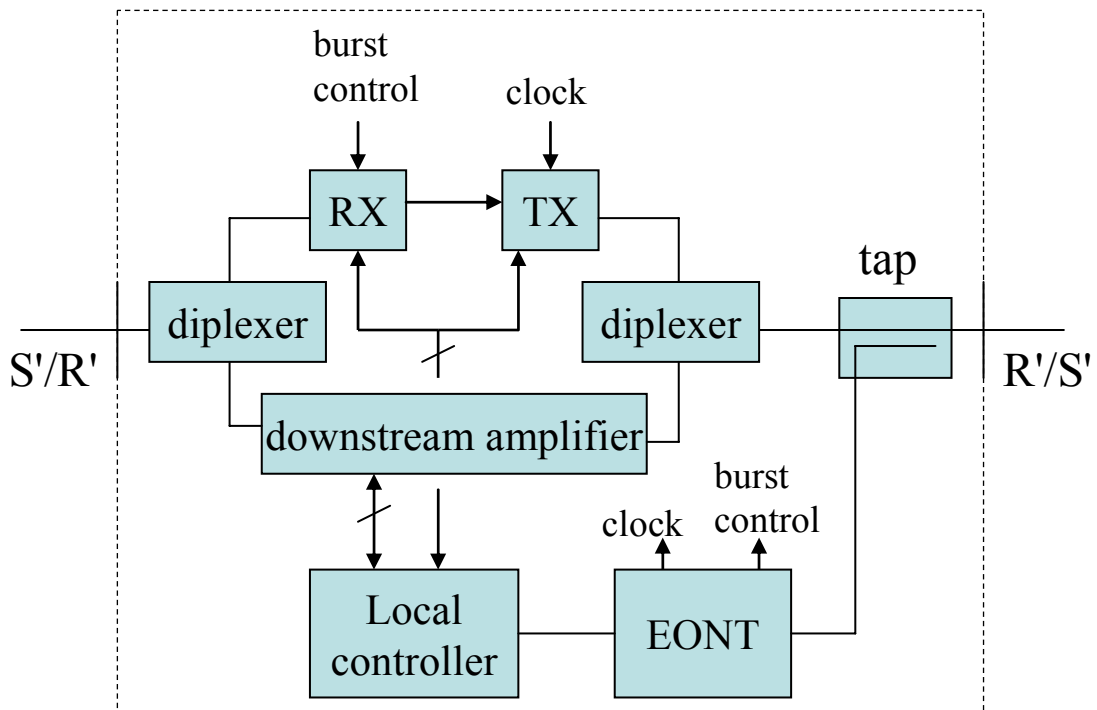


Figure 6 – OEO-type reach extender with embedded ONT for management purposes

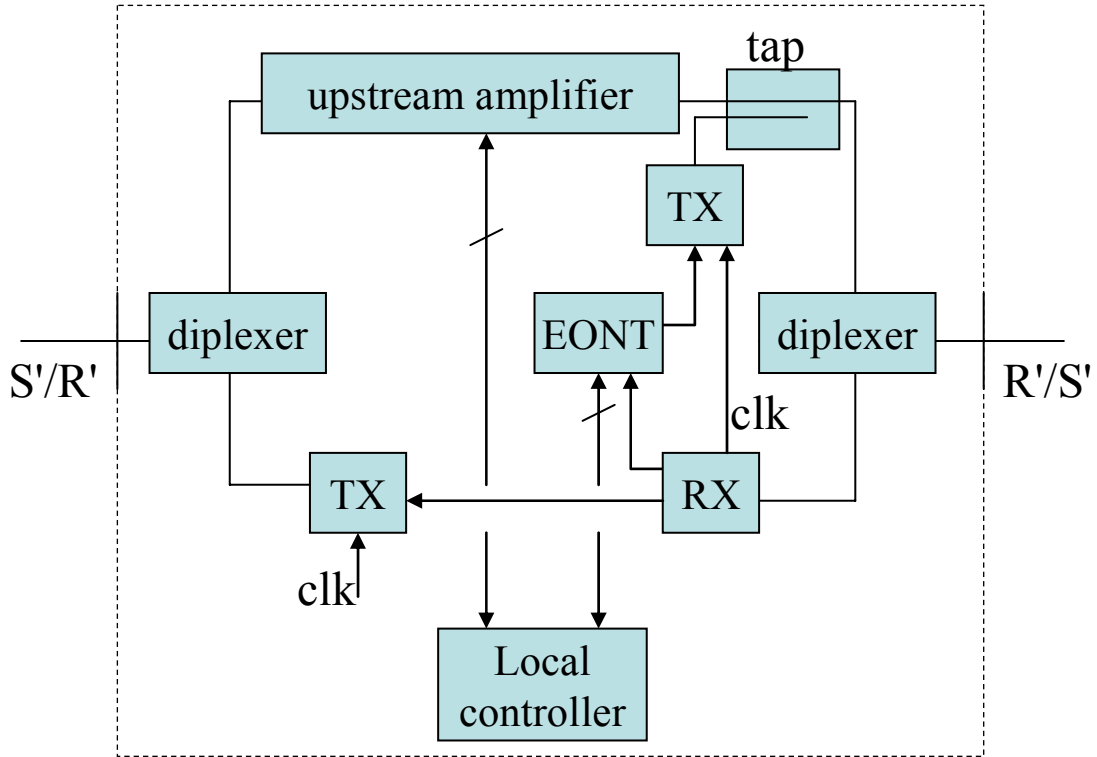
6.3 Hybrid architectures

A hybrid architecture using an optical amplifier for the downstream requires a clock reference for the upstream burst-mode receiver and transmitter. This has to be provided by an EONT used for management (refer to clause 7.2). Possible hybrid extender architectures are shown in Figure 7.

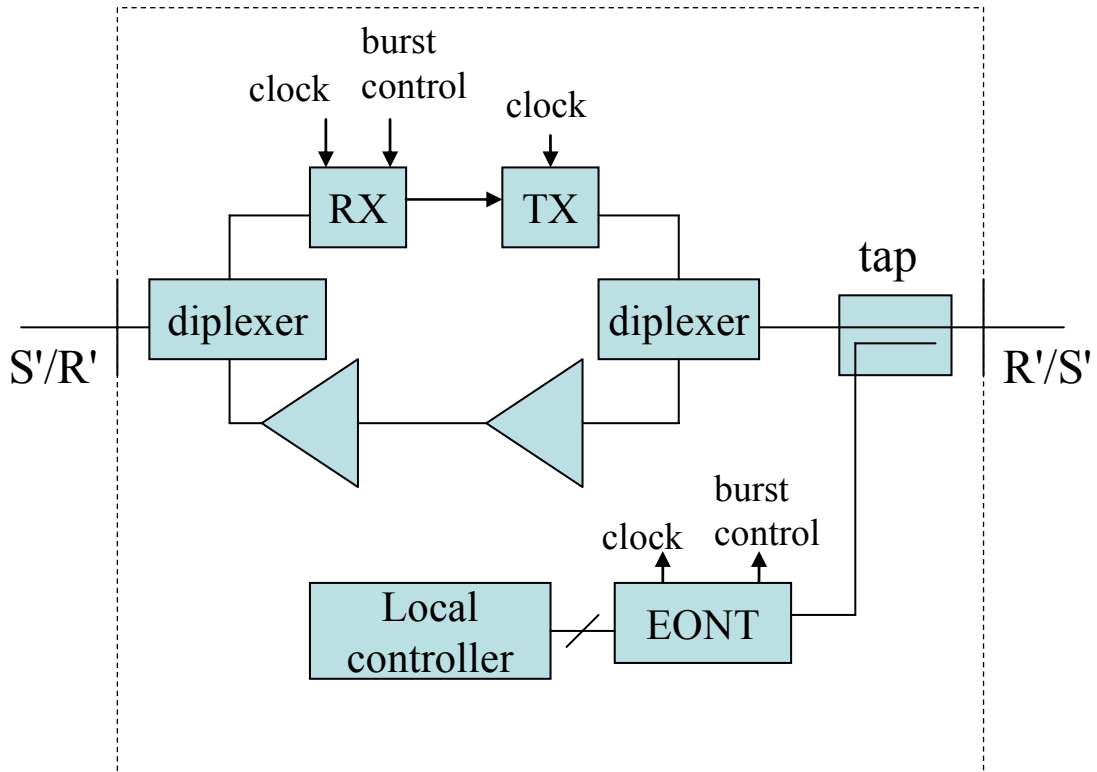
a)



b)



c)



d)

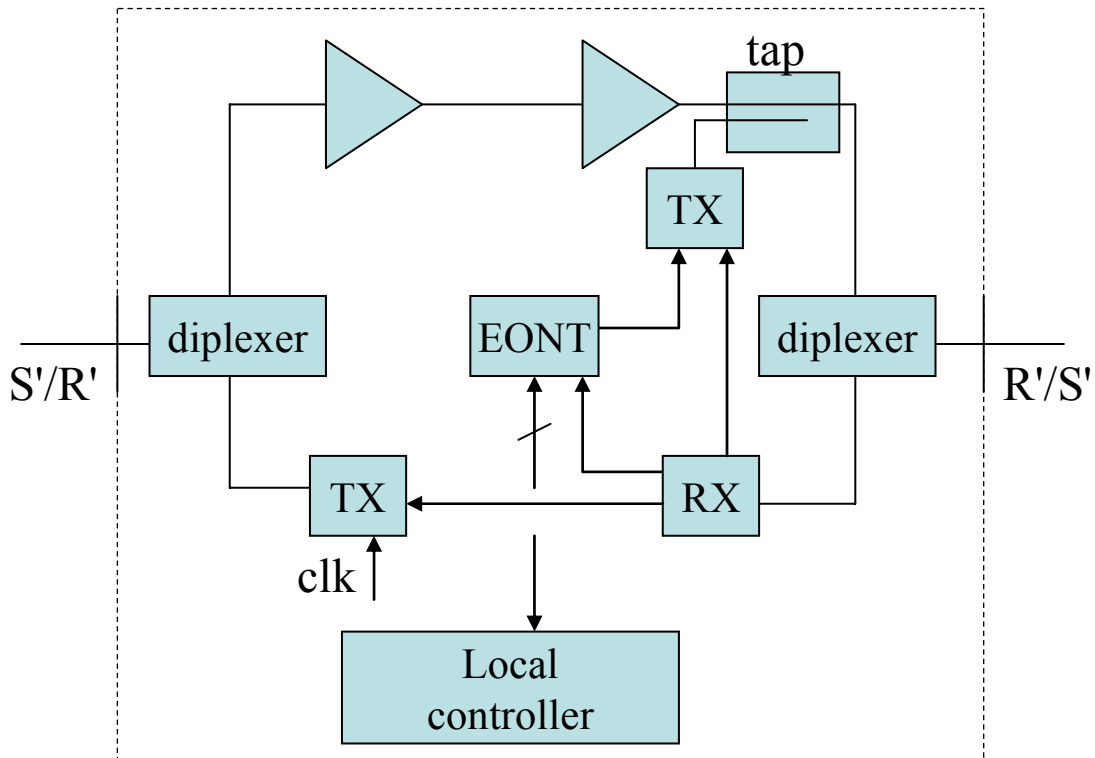


Figure 7 – Possible architectures for hybrid reach extenders

7 General requirements on GPON reach extenders

7.1 Compatibility

The reach extender must be compatible with existing GPON 2.4/1.2 Gbit/s class B+ rated ONT equipment and class B+ ODN. It is possible for the extender to support a more capable ODN, such as the class C+ defined in Amendment 2 to [ITU-T G.984.2].

The reach extender should be compatible with the existing class B+ OLT equipment to the maximum extent possible. There are physical factors that might make it difficult to support complete backward compatibility with the OLT, so some modification of the OLT may be necessary. However, it is envisioned that these modifications will be limited to parameter adjustments of the PMD and TC layers, and will not require wholesale hardware replacements.

7.2 Management

The reach extender must support full management of its configuration, performance monitoring and fault reporting. The scope of parameters under management depends on the extender type, and it may be that some of the OLT interface management features may not be supported in the extender.

The management of the extender should be provided using the OLT as a proxy. That is, the extender is considered to be an extension of the OLT network element, and no additional interface to the operator's management network will be provided. For early deployments, the extender may be managed as a network element directly by the element manager, in which case the EONT and OLT provide only Ethernet connectivity.

For the mid-span extender, the simplest way to accommodate these requirements is to furnish the extender equipment with the functions of an ONT (embedded ONT, EONT) to the extent that an OMCI channel can be established between the extender and the OLT. In some cases, some of the

functions of this ONT may be shared with those of the extender (for example, the PMD layer). The attributes that are specific to extenders will be described in [ITU-T G.984.4] as amended.

In hybrid schemes, the connection of the embedded ONT can be made in a similar manner, or the already available transmitter or receiver, respectively, can be reused.

There can be one EONT per reach extender or alternatively one shared EONT can provide a management interface to multiple reach extenders in a shelf (extender chassis).

The EONT should provide a dying gasp function.

7.3 Power

The mid-span extender will require electrical power. This may be an issue when the extender is located in the field. Also, the power source will need to have protection against failures of the primary power source, typically using batteries as a backup. Therefore, power consumption should be reduced as much as possible.

7.4 Out-of-scope issues

The following issues are of interest for reach extender technology, but are considered out-of-scope for the current standardization.

The reach extender may multiplex several GPON channels onto one fibre (or fibre pair) in the OTL. Multiplexing in time domain as in wavelength domain is possible. This is for further study.

Resilience in the presence of a reach extender may be required due to the extended reach. What may be protected (e.g., OTL, reach extender optics, OLT optics) and the possible approaches are for further study.

An individual reach extender may need to be transparent to not only GPON but other bit streams, such as a next generation access (NGA) system. This is for further study.

ITU-T Recommendations may consider in the future methods and physical layer planning rules to enable overlay of video and next generation access (NGA) systems in the presence of a reach extender. These possibilities and evaluation of crosstalk are for further study.

A reach extender compatible to both GPON and GE-PON is for further study.

8 Specifications for mid-span extenders

8.1 Optical trunk line

The optical parameters of the optical trunk line are given in Table 1.

Table 1 – Physical medium dependant layer parameters of OTL

Items	Unit	Specification
Fibre type	–	[ITU-T G.652]
Attenuation range for 1290-1330 nm range applicable for OEO type of extenders	dB	14-27.5 (Note 1)
Maximum attenuation for 1290-1330 nm range applicable for OA type of extenders	dB	28 (Note 2)
Minimum attenuation for 1290-1330 nm range applicable for OA type of extenders	dB	(Note 3)
Attenuation range for 1480-1500 nm range applicable for OEO type of reach extenders	dB	11-23 (Note 1)

Table 1 – Physical medium dependant layer parameters of OTL

Items	Unit	Specification
Maximum attenuation for 1480-1500 nm range applicable for OA type of reach extenders	dB	23 (Note 2)
Minimum attenuation for 1480-1500 nm range applicable for OA type of reach extenders	dB	(Note 3)
Maximum optical path penalty	dB	1
Maximum fibre distance between S/R and R'/S' points	km	60 minus the distance used in the ODN
Bidirectional transmission	–	1-fibre WDM
Maintenance wavelength	nm	To be defined
NOTE 1 – For lower attenuation values, external optical attenuators can be used.		
NOTE 2 – May be varied depending on implementation.		
NOTE 3 – OA implementation-dependent; for low attenuation values, an appropriately designed OA type extender or external optical attenuators can be used.		

8.2 Optical trunk line interface (R'/S') and OLT interface (S/R)

The optical parameters of the R'/S' and S/R interfaces are given in Tables 2a and 2b.

Table 2a – Optical interface parameters of 2488 Mbit/s downstream direction (OLT>Ext)

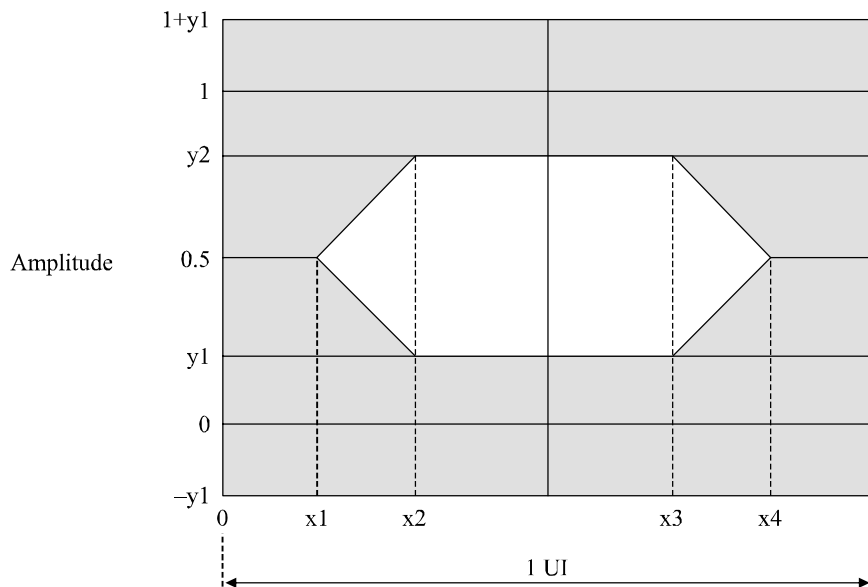
Items	Unit	OEO type	OA type
OLT transmitter			
Nominal bit rate	Mbit/s	2488.32	2488.32
Operating wavelength	nm	1480-1500	1480-1500
Line code	–	Scrambled NRZ	Scrambled NRZ
Mask of the transmitter eye diagram	–	Figure 8	Figure 8
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA	NA
Minimum ORL of OFT at S/R interface	dB	More than 32	More than 32
ODN class rating of the OLT interface		B+	B+
Mean launched power MIN	dBm	+1.5	+1.5
Mean launched power MAX	dBm	+5	+5
Launched optical power without input to the transmitter	dBm	NA	NA
Extinction ratio (Note 1)	dB	More than 8.2	More than 8.2
Tolerance to the transmitter incident light power	dB	More than –15	More than –15
If MLM laser – Maximum RMS width	nm	NA	NA
If SLM laser – Maximum –20 dB width (Note 2)	nm	1	1
If SLM laser – Minimum side mode suppression ratio	dB	30	30
Dispersion reach at 1 dB penalty	km	60	60

Table 2a – Optical interface parameters of 2488 Mbit/s downstream direction (OLT>Ext)

Items	Unit	OEO type	OA type
Extender receiver			
Maximum reflectance of equipment, measured at receiver wavelength	dB	Less than –20	NA
Bit error ratio	–	Less than 10^{-12}	NA
ODN class rating of the extender R'/S' interface		B+	B+
Minimum sensitivity (back-to-back)	dBm	–23	–23 (Note 3)
Minimum overload	dBm	–6	–5
Consecutive identical digit immunity	Bit	More than 72	more than 72
Jitter tolerance	–	Figure 9	NA
Tolerance to the reflected optical power	dB	Less than 10	NA
NOTE 1 – The extinction ratio of 8.2 dB is a relaxation of the former value of 10 dB. The new value does imply an improvement of the ONU receiver of 0.5 dB optical modulation amplitude.			
NOTE 2 – Values of maximum –20 dB width and minimum side mode suppression ratio are referred to in [ITU-T G.957].			
NOTE 3 – The minimum input power into the OA-type extender at R'/S' interface is –23 dBm in order to achieve a bit error ratio of 10^{-10} at the ONU.			

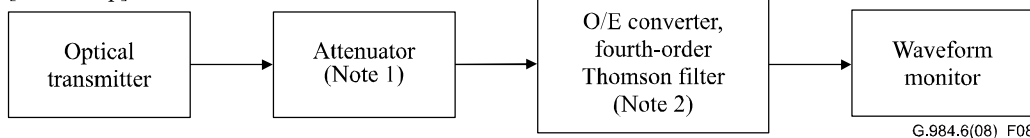
Mask of OLT transmitter eye diagram

In this Recommendation, general transmitter pulse shape characteristics, including rise time, fall time, pulse overshoot, pulse undershoot and ringing, all of which should be controlled to prevent excessive degradation of the receiver sensitivity, are specified in the form of a mask of the downstream transmitter eye diagram at S/R. For the purpose of an assessment of the transmit signal, it is important to consider not only the eye opening, but also the overshoot and undershoot limitations.



	1244.16 Mbit/s	2488.32 Mbit/s
x1/x4	0.28/0.72	---
x2/x3	0.40/0.60	---
x3 - x2	---	0.2
y1/y2	0.20/0.80	0.25/0.75

[Test set-up]

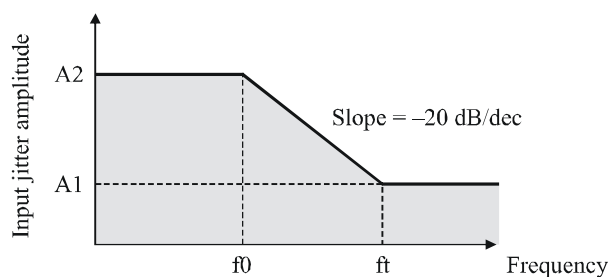


NOTE 1 – Attenuator is used if necessary.

NOTE 2 – Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

NOTE 3 – In the case of 2488.32 Mbit/s, x2 and x3 of the rectangular eye mask need not be equidistant with respect to the vertical axes at 0 UI and 1 UI. The extent of this deviation is for further study.

Figure 8 – Mask of the eye diagram for the OLT transmitter



Downstream bit rate (Mbit/s)	ft [kHz]	f0 [kHz]	A1 [UIp-p]	A2 [UIp-p]
1244.16	500	50	0.075	0.75
2488.32	1000	100	0.075	0.75

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Figure 9 – Jitter tolerance mask for extender downstream Rx

Jitter tolerance is defined as the peak-to-peak amplitude of sinusoidal jitter applied on the input PON signal that causes a 1-dB optical power penalty at the optical equipment. Note that it is a stress test to ensure that no additional penalty is incurred under operating conditions.

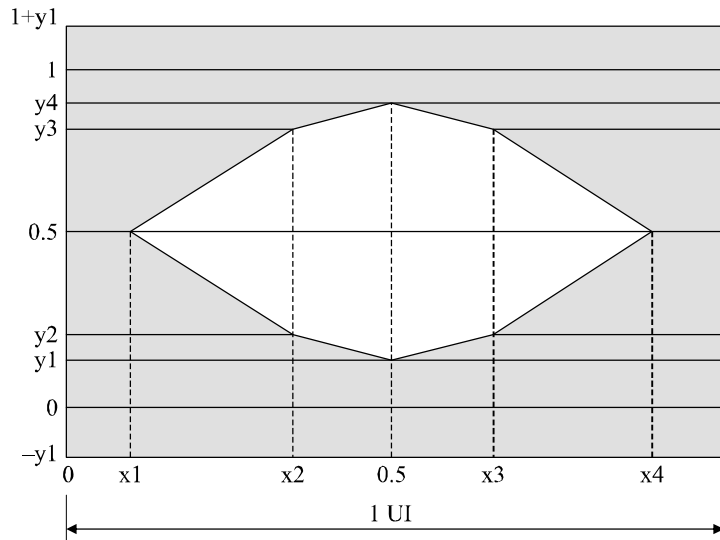
Extender shall tolerate, as a minimum, the input jitter applied according to the mask in Figure 9, with the parameters specified in that figure for each bit rate.

Table 2b – Optical interface parameters of 1244 Mbit/s upstream direction (Ext>OLT)

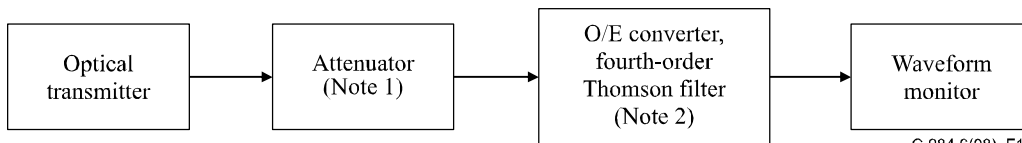
Items	Unit	OEO type	OA type
Extender transmitter			
Nominal bit rate	Mbit/s	1244.16	NA
Operating wavelength	nm	1290-1330	1290-1330 or 1300-1320 (Note 1)
Line code	–	Scrambled NRZ	NA
Mask of the transmitter eye diagram	–	Figure 10	NA
Maximum reflectance of equipment, measured at transmitter wavelength	dB	Less than –6	Less than –6
Minimum ORL of OFT at R'/S'	dB	More than 32	More than 32
ODN class rating of the extender R'/S'		B+	B+
Mean launched signal power MIN	dBm	0.5	(Note 2)
Mean launched signal power MAX	dBm	+5	(Note 2)
Launched optical power without input to the transmitter	dBm	Less than min sensitivity –10	NA
Maximum Tx enable (Note 3)	Bits	16	NA
Maximum Tx disable (Note 3)	Bits	16	NA
Extinction ratio	dB	More than 10	NA
Tolerance to transmitter incident light power	dB	More than –15	NA
MLM laser – Maximum RMS width	nm	NA	NA
SLM laser – Maximum –20 dB width (Note 4)	nm	1	NA

Table 2b – Optical interface parameters of 1244 Mbit/s upstream direction (Ext>OLT)

Items	Unit	OEO type	OA type
If SLM laser – Minimum side mode suppression ratio	dB	30	NA
Jitter transfer	–	Figure 11	NA
Jitter generation from 4.0 kHz to 10.0 MHz	UIp-p	0.33	NA
Maximum ASE output power in 1285-1335 nm band launched toward OLT relative to signal output power. Condition: –28 dBm signal input power at S'/R'.	dB	NA	7
Maximum ASE output power in 1200-1285 nm and 1335-1400 nm band launched toward OLT relative to signal output power. Condition: –28 dBm signal input power at S'/R'.	dB	NA	–4
Maximum ASE output power in 1400-1600 nm band launched toward OLT. Condition: –23 dBm signal input power at 1490 nm at R'/S'.	dBm	NA	2
OLT receiver			
Maximum reflectance of equipment, measured at receiver wavelength	dB	Less than –20	Less than –20
Bit error ratio	–	Less than 10^{-12} (Note 5)	Less than 10^{-10}
ODN class rating of the OLT interface		B+	B+
Minimum sensitivity (back-to-back)	dBm	–28	–28
Minimum overload	dBm	–8	–8
Consecutive identical digit immunity	Bit	More than 72	More than 72
Jitter tolerance	–	NA	NA
Tolerance to the reflected optical power	dB	Less than 10	Less than 10
Maximum penalty due to ASE-related power bias at OLT receiver	dB	NA	0.5
Immunity against incident ASE power (optical power bias tolerance) in 1285-1335 nm band at 0.5 dB additional penalty: ASE power relative to modulated signal power.	dB	NA	7 (Note 6)
<p>NOTE 1 – The narrow wavelength band option (1300-1320 nm, see [ITU-T G.984.5]) used in conjunction with an OBF with a corresponding pass-band may decrease ASE beat noise penalty, and relax OLT receiver immunity requirements against ASE power.</p> <p>NOTE 2 – Implementation-dependent. Values can be derived from the OA-type reach extender's gain specification and its allowed ODN attenuation range. Maximum and minimum signal output power may be determined from the following formulae:</p> $P_{out(max)} = +5 - \text{min ODN attenuation} + \text{maximum gain}$ $P_{out(min)} = +0.5 - \text{max ODN attenuation} + \text{minimum gain}$ <p>NOTE 3 – As defined in clause 8.2.6.3.1 of [ITU-T G.984.2].</p> <p>NOTE 4 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in [ITU-T G.957].</p> <p>NOTE 5 – Condition: –28 dBm, burst input power levels within ± 1 dB.</p> <p>NOTE 6 – ASE noise generated by the OA-type reach extender appears to the receiver as optical power bias (see Appendix I).</p>			



	155.52 Mbit/s	622.08 Mbit/s	1244.16 Mbit/s	2488.32 Mbit/s
x1/x4	0.10/0.90	0.20/0.80	0.22/0.78	For further study
x2/x3	0.35/0.65	0.40/0.60	0.40/0.60	For further study
y1/y4	0.13/0.87	0.15/0.85	0.17/0.83	For further study
y2/y3	0.20/0.80	0.20/0.80	0.20/0.80	For further study



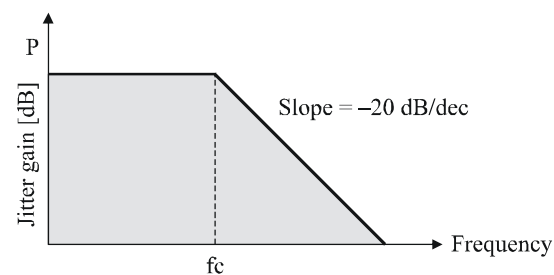
G.984.6(08)_F10

NOTE 1 – Attenuator is used if necessary.

NOTE 2 – Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure 10 – Mask of the eye diagram for the extender upstream transmitter

The mask of the eye diagram for the upstream direction burst mode signal is applied to from the first bit of the preamble to the last bit of the burst signal, inclusive. This does not apply to the optical power set-up procedure (refer to clause 8.2.4 of [ITU-T G.984.3]).



Downstream bit rate (Mbit/s)	fc [kHz]	P [dB]
1244.16	1000	0.1
2488.32	2000	0.1

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Figure 11 – Jitter transfer for extender upstream transmitter

The jitter transfer function is defined as:

$$jitter\ transfer = 20 \log_{10} \left[\frac{jitter\ on\ upstream\ extender\ signal\ UI}{jitter\ on\ downstream\ OLT\ signal\ UI} \times 2 \right]$$

The jitter transfer function of an extender shall be under the curve given in Figure 11, when input sinusoidal jitter up to the mask level in Figure 9 is applied, with the parameters specified in this figure for each bit rate.

8.3 Optical distribution network

This optical parameters of the optical distribution network are given in Table 3.

Table 3 – Physical medium dependant layer parameters of ODN

Items	Unit	Specification
Fibre type	–	[ITU-T G.652]
Attenuation range for 1260-1360 nm range applicable for OEO type of reach extenders	dB	13-28
Attenuation range for 1290-1330 nm range applicable for OA type of reach extenders	dB	13-28 (Note 1)
Maximum loss difference for 1290-1330 nm applicable for OA type of reach extenders	dB	(Note 2)
Attenuation range for 1480-1500 nm range	dB	13-28
Maximum optical path penalty	dB	0.5
Maximum fibre distance between S'/R' and R/S points	km	20
Bidirectional transmission	–	1-fibre WDM
Maintenance wavelength	nm	To be defined
NOTE 1 – May be varied depending on implementation.		
NOTE 2 – Implementation-dependent. The range can be derived from the operational data provided and the particular OTL loss.		

8.4 Extender interface to optical distribution network (S'/R') and ONU interface (R/S)

The optical parameters of the S'/R' and R/S interfaces are given in Tables 4a and 4b.

Table 4a – Optical interface parameters of 2488 Mbit/s downstream direction (Ext>ONU)

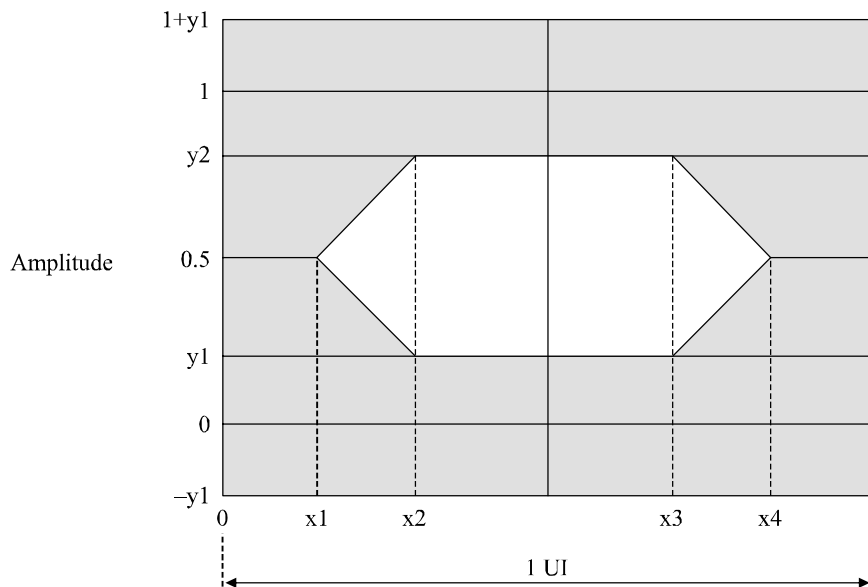
Items	Unit	OEO type	OA type
Extender transmitter			
Nominal bit rate	Mbit/s	2488.32	NA
Operating wavelength	nm	1480-1500	1480-1500
Line code	–	Scrambled NRZ	NA
Mask of the transmitter eye diagram	–	Figure 12	NA
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA	NA
Minimum ORL of ODN at S'/R'	dB	More than 32	More than 32
ODN class rating of the extender S'/R'		B+	B+
Mean launched power MIN	dBm	+1.5	(Note 1)
Mean launched power MAX	dBm	+5	(Note 1)
Launched optical power without input to the transmitter	dBm	NA	NA
Extinction ratio	dB	more than 10	NA
Tolerance to the transmitter incident light power	dB	more than –15	NA
If MLM laser – Maximum RMS width	nm	NA	NA
If SLM laser – Maximum –20 dB width (Note 2)	nm	1	NA
If SLM laser – Minimum side mode suppression ratio	dB	30	NA
Jitter transfer	–	Figure 13	NA
Jitter generation from 5.0 kHz to 20.0 MHz	UIp-p	0.3	NA
Maximum ASE power in 1400-1600 nm band launched toward ONUs relative to the launched output signal power. Condition: –23 dBm signal input power at R'/S'.	dB	NA	5
Maximum ASE output power in 1200-1400 nm band launched toward ONUs. Condition: –28 dBm 1310 nm signal input power at S'/R'	dBm	NA	9
ONU receiver			
Maximum reflectance of equipment, measured at receiver wavelength	dB	Less than –20	Less than –20
Bit error ratio	–	Less than 10 ⁻¹⁰	Less than 10 ⁻¹⁰
ODN class rating of the ONU interface		B+	B+
Minimum sensitivity (back-to-back)	dBm	–27	–27
Minimum overload	dBm	–8	–8
Consecutive identical digit immunity	Bit	More than 72	More than 72
Jitter tolerance	–	Figure 14	Figure 14
Tolerance to the reflected optical power	dB	Less than 10	Less than 10
Additional penalty due ASE-related power bias at ONU receiver	dB	NA	0.5 dB

Table 4a – Optical interface parameters of 2488 Mbit/s downstream direction (Ext>ONU)

Items	Unit	OEO type	OA type
Immunity against incident ASE power (optical power bias tolerance) in 1400-1600 nm band at 0.5 dB additional penalty: ASE power relative to signal power.	dB	NA	5 (Note 3)
<p>NOTE 1 – Implementation-dependent. Values can be derived from the OA-type reach extender's gain and the OTL loss. Maximum and minimum signal output power may be determined by:</p> $P_{out}(\min) = 1.5 + \text{minimum gain} - \text{OTL loss}$ $P_{out}(\max) = 5.0 + \text{maximum gain} - \text{OTL loss}$ <p>As an option, the gain can be adjusted to optimize performance (ODN attenuation range).</p> <p>NOTE 2 – Values of maximum –20 dB width and minimum side mode suppression ratio are referred to in [ITU-T G.957].</p> <p>NOTE 3 – ASE generated by the OA extender appears to the receiver as optical power bias. See Appendix I.</p>			

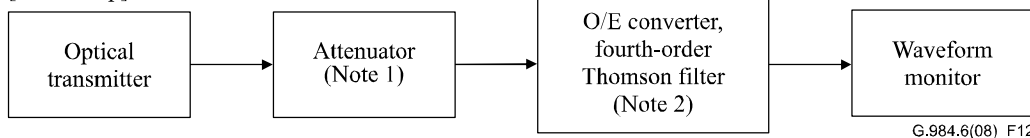
Mask of transmitter eye diagram

In this Recommendation, general transmitter pulse shape characteristics, including rise time, fall time, pulse overshoot, pulse undershoot and ringing, all of which should be controlled to prevent excessive degradation of the receiver sensitivity, are specified in the form of a mask of the downstream transmitter eye diagram at the extender S'/R' interface. For the purpose of an assessment of the transmit signal, it is important to consider not only the eye opening, but also the overshoot and undershoot limitations.



	1244.16 Mbit/s	2488.32 Mbit/s
x1/x4	0.28/0.72	---
x2/x3	0.40/0.60	---
x3 - x2	---	0.2
y1/y2	0.20/0.80	0.25/0.75

[Test set-up]

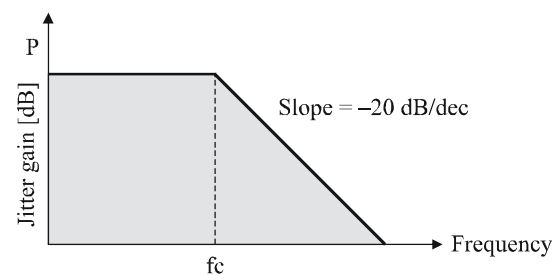


NOTE 1 – Attenuator is used if necessary.

NOTE 2 – Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

NOTE 3 – In the case of 2488.32 Mbit/s, x2 and x3 of the rectangular eye mask need not be equidistant with respect to the vertical axes at 0 UI and 1 UI. The extent of this deviation is for further study.

Figure 12 – Mask of the eye diagram for the extender downstream transmitter



Downstream bit rate (Mbit/s)	fc [kHz]	P [dB]
1244.16	1000	0.1
2488.32	2000	0.1

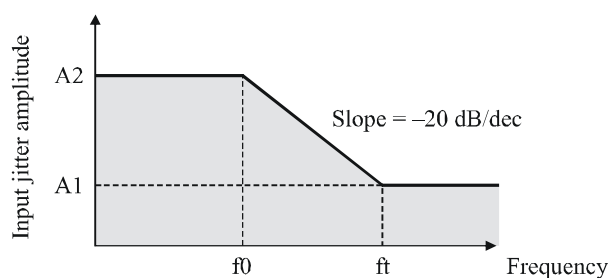
G.984.6(08)_F13

Figure 13 – Jitter transfer for extender downstream transmitter

The jitter transfer function is defined as:

$$jitter\ transfer = 20 \log_{10} \left[\frac{jitter\ on\ extender\ downstream\ transmitter\ signal\ UI}{jitter\ on\ received\ OLT\ signal\ UI} \right]$$

The downstream jitter transfer function of an extender shall be under the curve given in Figure 13, when input sinusoidal jitter up to the mask level in Figure 9 is applied, with the parameters specified in this figure for each bit rate.



Downstream bit rate (Mbit/s)	ft [kHz]	f0 [kHz]	A1 [UIp-p]	A2 [UIp-p]
1244.16	500	50	0.075	0.75
2488.32	1000	100	0.075	0.75

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Figure 14 – Jitter tolerance mask for ONU Rx

Jitter tolerance is defined as the peak-to-peak amplitude of sinusoidal jitter applied on the input PON signal that causes a 1-dB optical power penalty at the optical equipment. Note that it is a stress test to ensure that no additional penalty is incurred under operating conditions.

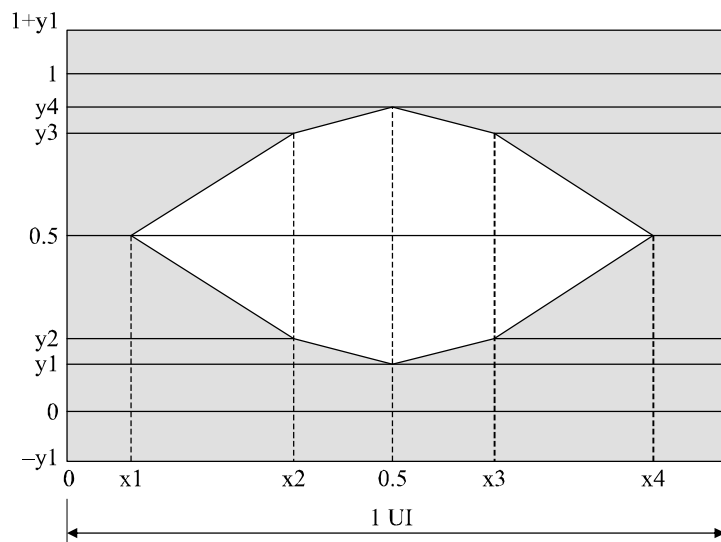
The ONU shall tolerate, as a minimum, the input jitter applied according to the mask in Figure 14, with the parameters specified in that figure for each bit rate.

Table 4b – Optical interface parameters of 1244 Mbit/s upstream direction (ONU>Ext)

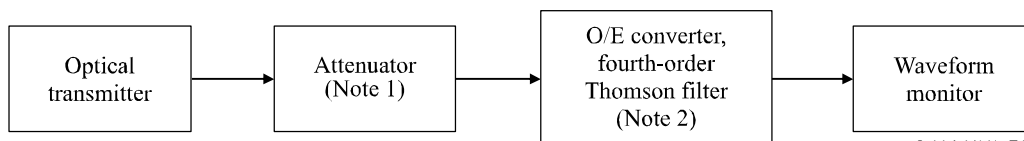
Items	Unit	OEO Type	OA type
ONU transmitter			
Nominal bit rate	Mbit/s	1244.16	1244.16
Operating wavelength	nm	1260-1360	1290-1330 or 1300-1320 (Note 1)
Line code	–	Scrambled NRZ	Scrambled NRZ
Mask of the transmitter eye diagram	–	Figure 15	Figure 15
Maximum reflectance of equipment, measured at transmitter wavelength	dB	Less than –6	Less than –6
Minimum ORL of ODN at R/S interface	dB	More than 32	More than 32
ODN class rating of the ONU interface		B+	B+
Mean launched power MIN	dBm	+0.5	+0.5
Mean launched power MAX	dBm	+5	+5
Launched optical power without input to the transmitter	dBm	Less than min sensitivity –10	Less than min sensitivity –10
Maximum Tx enable (Note 2)	bits	16	16
Maximum Tx disable (Note 2)	bits	16	16
Extinction ratio	dB	More than 10	More than 10
Tolerance to transmitter incident light power	dB	More than –15	More than –15
MLM laser – Maximum RMS width	nm	NA	NA
SLM laser – Maximum –20 dB width (Note 3)	nm	1	1
If SLM laser – Minimum side mode suppression ratio	dB	30	30
Jitter transfer	–	Figure 16	Figure 16
Jitter generation from 4.0 kHz to 10.0 MHz	UIp-p	0.33	0.33
Dispersion reach at 1 dB penalty	km	20	60
Extender receiver			
Maximum reflectance of equipment, measured at receiver wavelength	dB	Less than –20	Less than –20
Bit error ratio	–	Less than 10^{-10}	NA
ODN Class rating of the extender S'/R'		B+	B+
Minimum sensitivity	dBm	–28	–28 (Note 4)
Minimum overload	dBm	–8	–8
Consecutive identical digit immunity	Bit	More than 72	NA
Jitter tolerance	–	NA	NA

Table 4b – Optical interface parameters of 1244 Mbit/s upstream direction (ONU>Ext)

Items	Unit	OEO Type	OA type
Tolerance to the reflected optical power	dB	Less than 10	NA
<p>NOTE 1 – Narrow wavelength band option (1300-1320 nm) used in conjunction with an OBF with a corresponding pass-band, may decrease ASE beat noise penalty and relax OLT receiver immunity requirements against ASE power. Further, the narrow wavelength band option, together with a RS(255,239) FEC is used to form a class C+ ODN. See [ITU-T G.984.5], and Amendment 2 to [ITU-T G.984.2].</p> <p>NOTE 2 – As defined in clause 8.2.6.3.1 of [ITU-T G.984.2].</p> <p>NOTE 3 – Values of maximum –20 dB width and minimum side mode suppression ratio are referred to in [ITU-T G.957].</p> <p>NOTE 4 – The minimum input power into the OA-type extender at S'/R' interface is –28 dBm in order to achieve a bit error ratio of 10^{-10} at the OLT. In case of class C+ ODN operation, the minimum input power into the OA-type extender at S'/R' interface is –32 dBm.</p>			



	155.52 Mbit/s	622.08 Mbit/s	1244.16 Mbit/s	2488.32 Mbit/s
x1/x4	0.10/0.90	0.20/0.80	0.22/0.78	For further study
x2/x3	0.35/0.65	0.40/0.60	0.40/0.60	For further study
y1/y4	0.13/0.87	0.15/0.85	0.17/0.83	For further study
y2/y3	0.20/0.80	0.20/0.80	0.20/0.80	For further study



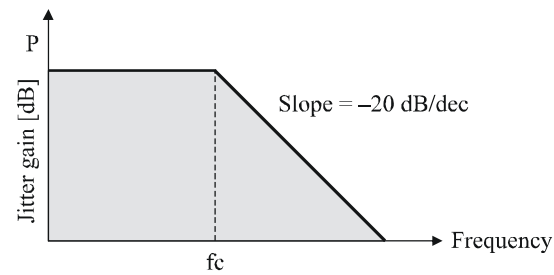
G.984.6(08)_F15

NOTE 1 – Attenuator is used if necessary.

NOTE 2 – Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure 15 – Mask of the eye diagram for the ONU transmitter

The mask of the eye diagram for the upstream direction burst mode signal is applied to from the first bit of the preamble to the last bit of the burst signal, inclusive. This does not apply to the optical power set-up procedure (refer to clause 8.2.4 of [ITU-T G.984.3]).



Downstream bit rate (Mbit/s)	fc [kHz]	P [dB]
1244.16	1000	0.1
2488.32	2000	0.1

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Figure 16 – Jitter transfer for ONU transmitter

The jitter transfer function is defined as:

$$jitter\ transfer = 20\log_{10} \left[\frac{jitter\ on\ ONU\ upstream\ signal\ UI}{jitter\ on\ received\ extender\ downstream\ signal\ UI} \times 2 \right]$$

The jitter transfer function of an ONU shall be under the curve given in Figure 16, when input sinusoidal jitter up to the mask level in Figure 14 is applied, with the parameters specified in this figure for each bit rate.

8.5 TC layer impacts

The introduction of an OEO reach extender into the PON signal path will cause some degradation of the total burst mode overhead. For most OEO type systems, the extender's own burst mode receiver must accomplish level and/or clock recovery. For some OA type systems, there may be a short time interval from when the burst first arrives at the OA to when the gain control mechanisms have stabilized. The extender essentially 'consumes' an interval of the preamble pattern for its own adjustment before it can begin to transmit high-quality preamble upstream toward the OLT.

The OLT and ONT must compensate for this by allowing extra preamble pattern to be transmitted before each burst. The exact amount of extra preamble depends on the design of the extender, and is best determined during operation via the extender management channel. It is expected that reach extenders would require no more preamble than an OLT receiver, and potentially less.

The basic procedure for network commissioning is as follows:

Step 1: The OLT broadcasts the overhead and extended overhead messages on the PON.

Step 2: The OLT activates the reach extender (i.e., ranges and establishes the OMCI channel).

Step 3: The OLT obtains via the OMCI the reach extender's preamble requirement.

Step 4: The OLT broadcasts a revised extended overhead message that includes the reach extender's extra preamble requirement. Note that the reach extender will disregard this message.

Step 5: The OLT activates all the ONUs downstream of the extender now that the upstream channel has been properly aligned.

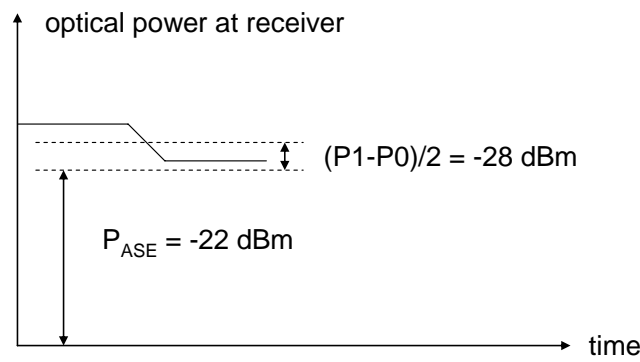
Appendix I

Implications on OLT receivers due to insertion of OA type extenders

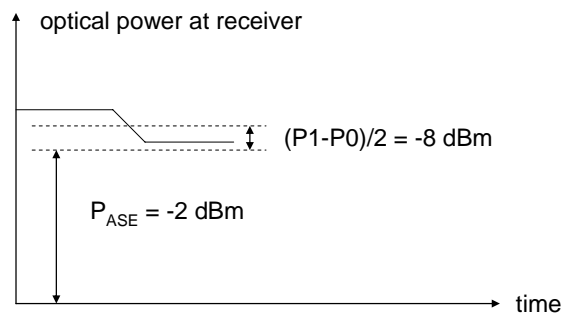
(This appendix does not form an integral part of this Recommendation)

Semiconductor optical amplifiers (SOAs) are presently the most practical gain element for implementing OA-type of extenders. The amplified spontaneous emission (ASE) generated by the SOA appears at the R/S interface as a broadband light source, which is converted by the photodetector section of the receiver to a DC bias current and a noise term in the electrical domain. This appendix describes the implications of this optical power bias for the receiver.

Figure I.1 illustrates the effect of the ASE-based DC bias current on the decision threshold at the upstream receiver's sensitivity limit and overload limit, respectively. A receiver will function correctly only if it can tolerate this DC bias current with a maximum 0.5 dB power penalty over its entire input range.



(a) Optical power bias tolerance at the limit of OLT sensitivity (see Table 2b)



(b) Optical power bias tolerance at maximum OLT receive power (see Table 2b)

Figure I.1 – Optical power bias tolerance at the OLT upstream receiver

Generally, OLT receivers that are AC coupled, and those that are DC coupled but readjust their decision thresholds at the beginning of each received burst will be tolerant of DC bias. GPON OLT receiver implementations typically fall into one of these categories.

In both the upstream and downstream directions, a significant portion of the ASE power spectrum falls outside the nominal operating wavelength band of the OLT or ONU transmitter. The specifications given in Table 2b assume usage of an OBF to block upstream ASE directed to the OLT outside the operating band of the ONU transmitter. As an option, an OBF may also be used to block ASE directed towards ONU outside the operating band of the OLT transmitter.

OBFs improve performance by reducing ASE-ASE beat noise at the receiver and by relaxing the optical power bias tolerance requirements at the receivers.

It shall be noted that the excess backward ASE in upstream direction produced by the downstream OA need not be filtered out. The OBF should not interfere with video wavelengths, NGA wavelengths or supervisory wavelengths, since both OEO and OA extenders would likely use WDM technology to accommodate other wavelengths. In the example below, a video overlay signal at 1550 nm operates in a region where an OA extender may produce a significant amount of ASE. As shown in Figure I.2, WDM1 would block 1550 nm backward ASE from reaching the video OLT, and WDM2 would keep forward ASE at 1550 nm away from the video receiver.

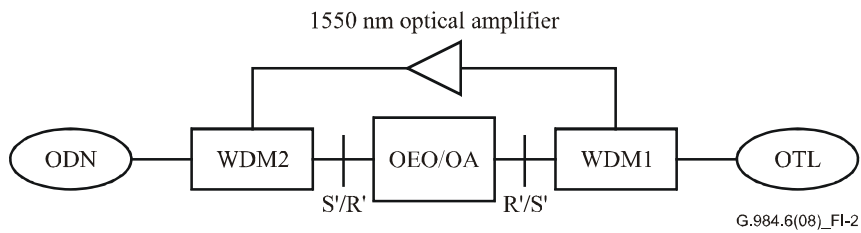


Figure I.2 – Forward and backward ASE filtering due to WDM overlay

Appendix II

Possible realization of an OA-based extender

(This appendix does not form an integral part of this Recommendation)

II.1 Introduction

The normative text of this Recommendation presents a "black-box" specification for an OA extender. The "black-box" specification is implementation-independent. This appendix provides example specifications for an SOA-based OA extender which meets the requirements of the normative text.

The link performance of an OA extender is a function of intrinsic properties of an amplifier (e.g., gain, noise figure and saturated output power) and of properties of other network elements (e.g., transmitter power and receiver sensitivity). The normative text and this appendix assume OLT and ONT transceivers as specified in Appendix III of [ITU-T G.984.2] for operation in an ODN with a class B+ loss budget. Thus, given amplifier design specifications, the link budget can be calculated.

II.2 Constraints on the link budget

The limitations on the link budget are given by:

- Amplifier gain and gain variation.
- Amplifier noise figure.
- Amplifier maximum saturated output power.
- Maximum receiver input power.

Saturated output power limits the input power to the extender. As SOA gain approaches saturation, the waveform/eye diagram of the SOA output signal can become distorted. Saturated output power for SOA devices are typically specified in terms of saturated CW output power at which the gain is either 1 dB or 3 dB below its unsaturated gain. These specifications are denoted P^{sat} (1 dB) and P^{sat} (3 dB), respectively. Typically, they are measured with a CW laser source.

There is not a simple relationship between the depth of saturation and distortion and the resultant bit error ratio (BER). This can depend on other parameters such as SOA and laser chirp contributions. Generally, for NRZ waveforms, when the *average* signal power from the SOA output is less than P^{sat} (1 dB) there is little impact on BER.

For the purposes of this Appendix, P^{sat} is the *average* signal output power at which a 1 dB power penalty is seen by the receiver at its maximum sensitivity under amplified conditions. P^{sat} is linked to a small signal gain at $P_{\text{in}} = P_{\text{min}}$, G and must be measured under constant SOA drive current (this will yield an adiabatic P^{sat}).

The link budget is constrained by P^{sat} , which limits the usable output power of the extender, and by the 60-km logical reach of the GPON.

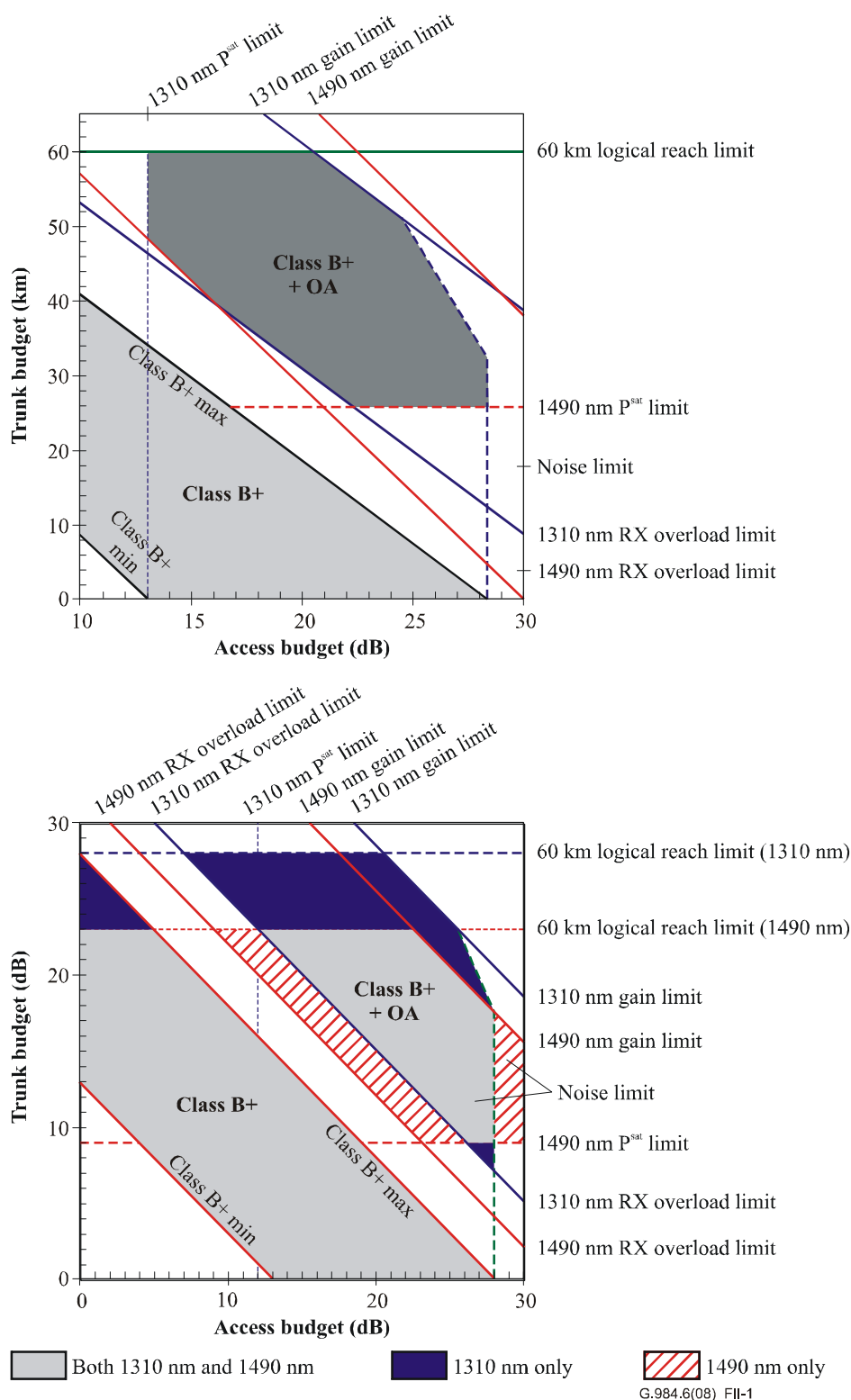
II.3 Amplifier design parameters

Table II.1 provides a template for the set of amplifier parameters necessary to select and configure a device suitable for a particular link. The minimum information which must be specified for the OA type extender in order to calculate maximum and minimum launch power levels are minimum and maximum gain figures for both upstream and downstream direction (refer to Tables 2b and 4a).

Table II.1 – Amplifier specification for an OA extender

Upstream parameters		
Minimum optical gain (over all polarizations, over 1290-1330 nm) at –28 dBm input power	dB	G_{1310}
Maximum optical gain (over all polarizations, over 1290-1330 nm) at –28 dBm input power. (Note)	dB	$G_{1310} + \Delta G_{1310}$
Minimum saturated output power (as defined in clause II.2), with amplifier current set for gain = G_{1310} dB at –28 dBm average optical input power, at 1.25 Gbit/s data rate and –28 dBm receiver sensitivity	dBm	P_{1310}^{sat}
Maximum noise figure at –28 dBm input power (over all polarizations, over 1290-1330 nm)	dB	NF_{1310}
Downstream parameters		
Minimum optical gain (over all polarizations, over 1480-1500 nm) at –23 dBm input power.	dB	G_{1490}
Maximum optical gain (over all polarizations, over 1480-1500 nm) at –23 dBm input power. (Note)	dB	$G_{1490} + \Delta G_{1490}$
Minimum saturated output power (as defined in clause II.2), with amplifier current set for gain = G_{1490} dB at –23 dBm average optical input power, at 2.5 Gbit/s data rate and –28 dBm receiver sensitivity	dBm	P_{1490}^{sat}
Maximum noise figure at –28 dBm input power (over all polarizations, over 1480-1500 nm)	dB	NF_{1490}
NOTE – This takes into account polarization-dependent gain.		

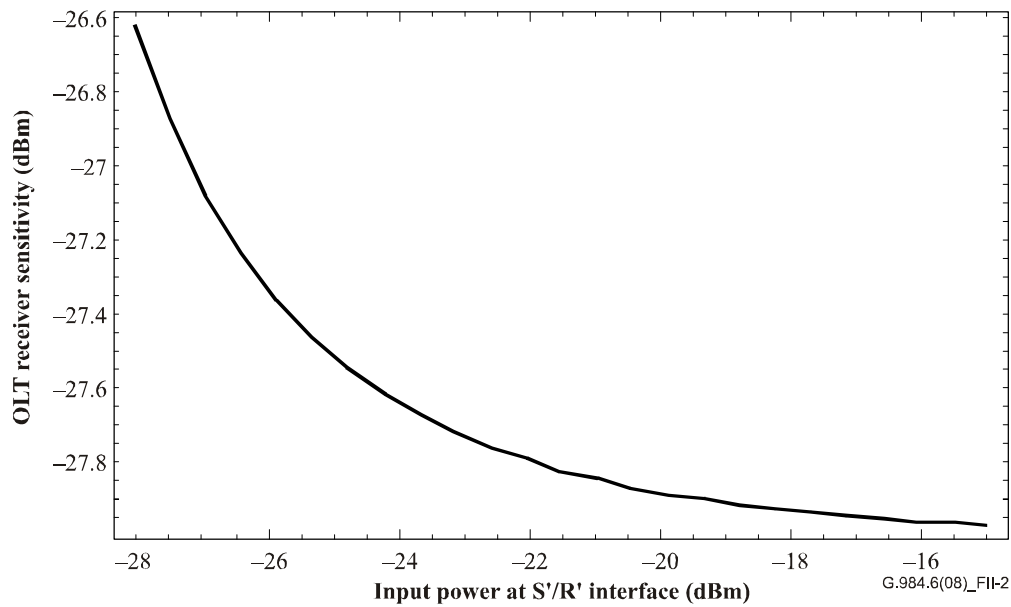
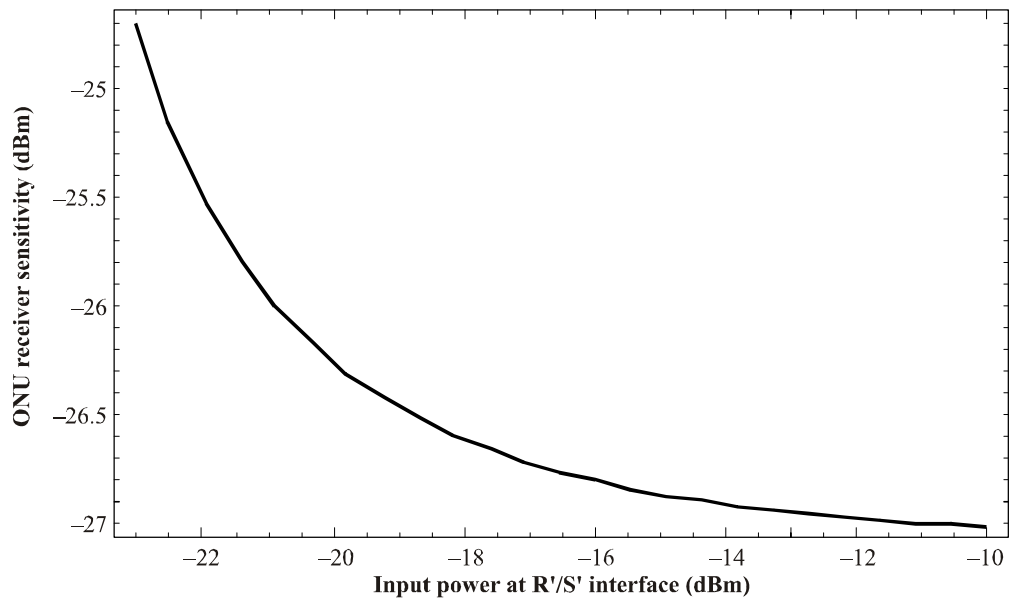
Figure II.1 shows an example of the operating region for a GPON. Such a diagram is sufficient to determine the suitability of the OA type extender with respect to ODN budget, trunk budget (or length) and the allowed differential loss in the ODN at a given trunk loss.



NOTE – Non-extended class B+ GPON shown for comparison. Upper figure showing OTL reach lower figure showing OTL loss.

Figure II.1 – Operating region for a GPON extended by the OA extender (example)

There is a penalty due to ASE, which depends on the input power of the reach extender. The vendor should provide a sensitivity plot, similar to the one shown in Figure II.2 to supports troubleshooting. This chart helps to figure out the minimum applicable sensitivity of the ONT and OLT receiver under extender operation.



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Figure II.2 – ONU (upper) and OLT (lower) sensitivity versus extender input power (typical example)

Appendix III

Protection

(This appendix does not form an integral part of this Recommendation)

III.1 Introduction

Protection architectures and solutions with GPON reach extenders are for further study. However, GPON reach extension has an impact on reliability. Due to long link length, the risk of a fibre damage is higher so, basically, the OTL will have to be protected.

On the other hand, GPON reach extension enables OLT-geo-redundancy, which is not yet fully standardized.

Figure III.1 gives one example of a protected reach extended GPON.

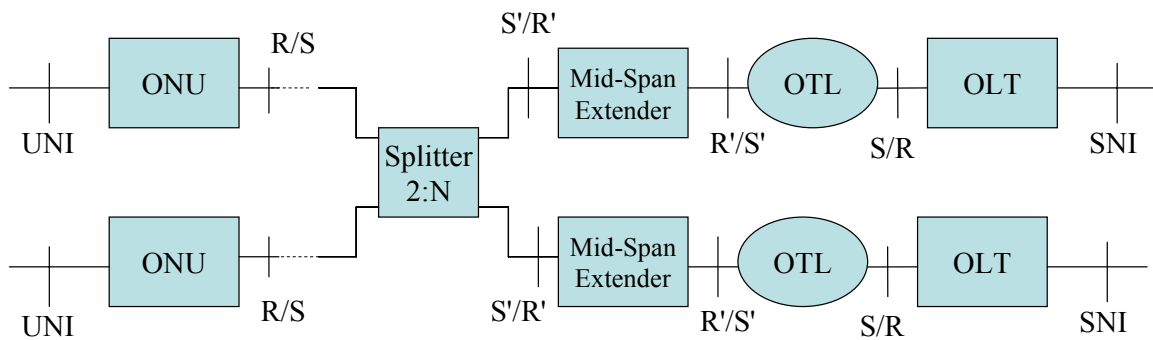


Figure III.1 – Reach extended GPON, with geo-redundant OLT and trunk line protection

Protection of extended reach GPON is for further study.

Appendix IV

Class C+ operation

(This appendix does not form an integral part of this Recommendation)

Reach extenders may support a class C+ interface at the S'/R' interface (in analogy to the reach extended C+ OLT S/R interface defined in Amendment 2 to [ITU-T G.984.2]).

In the OTL, an attenuation range of 18-31 dB can be supported if a class C+ interface is employed at the OLT. Here one dB margin is considered in order to keep the bit-error contribution in the OTL negligible.

Conditions for class C+ operation are:

- Availability of RS(255,239) FEC at ONU and OLT.

Appendix V

Optical time domain reflectometer

(This appendix does not form an integral part of this Recommendation)

V.1 Introduction

OTDR monitoring pulses may disturb the operation of the reach extender and, on the other hand, the presence of a reach extender blocks the propagation of the OTDR signals.

V.2 Solution

Figure V.1 gives one example of an extended GPON equipped with OTDR blocking filters or bypass filters. In both cases, insertion loss of the blocking or bypass filters has to be accounted into the OTL and/or the ODN loss. In case of bypass, one has to consider the reach limit of the OTDR in use.

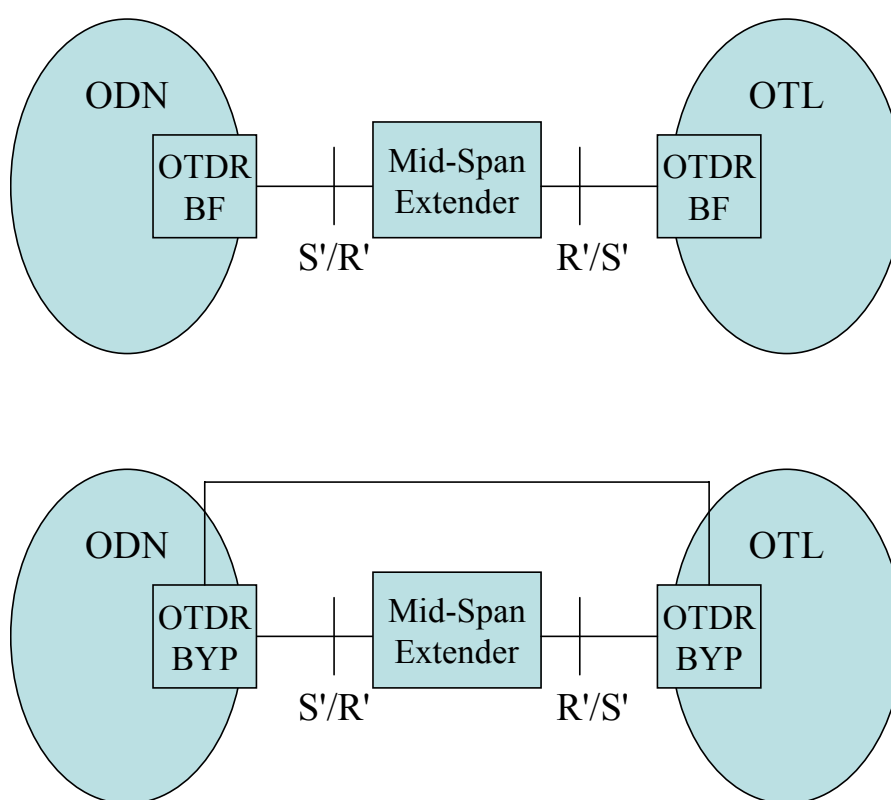


Figure V.1 – Reach extender with OTDR blocking filters (BF) and OTDR bypass (BYP) filters

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